Searching for New Physics through Charm at CDF

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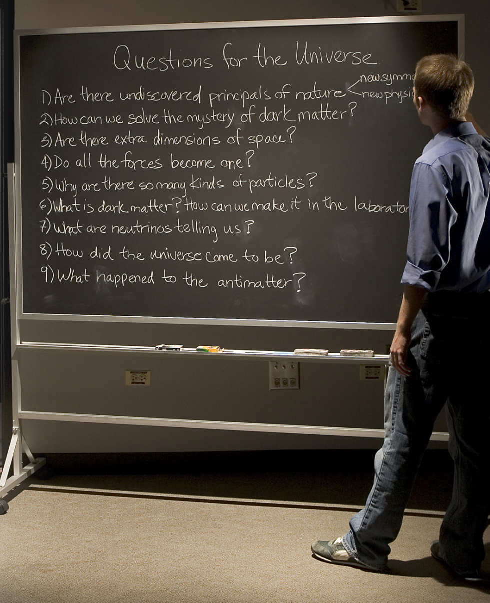
Searching for New Physics

- The Standard Model explains all experimental phenomena with good precision, but there are still many open questions unresolved
- Strong prejudice: there must be New Physics
- Precise measurements in the flavour sector: a possible way to look for massive particles or new couplings that are currently unaccessible through direct searches



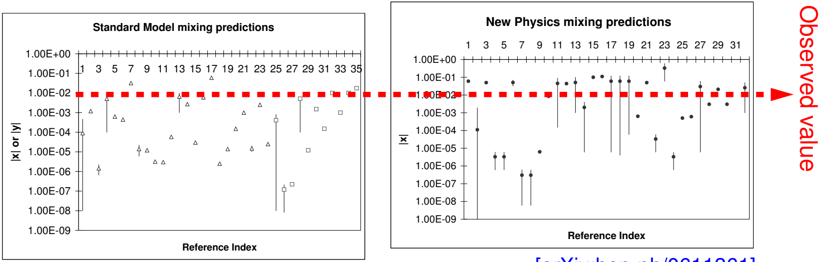
CP violation in the Charm sector

- CP violation observed so far is not sufficient to explain the matter-antimatter asymmetry of the Universe, so there might be something else...
- Until recently most CP violation measurements have been done in the area of down-quarks (s, b), so what about up-quarks? Why not look where we did not look before?
- Charm is a unique case
  - it probes the up-quark sector (unaccessible through t or u quarks)
  - transitions between first two generations of quarks have real CKM parameters, any asymmetry at current sensitivity would unambigously reveal NP

$$
\begin{array}{cc}
 & \begin{array}{ccc} d & s & b \end{array} \\
V_{\text{CKM}} = & \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} \begin{array}{c} u \\ c \\ t \end{array}
\end{array}
$$

Charm mixing "anomaly"

- Observed D^0 mixing rate is large, consistent only with most stretched SM predictions



[arXiv:hep-ph/0611361]

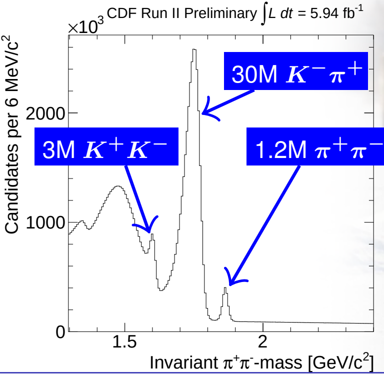
- Could this be a first hint of NP?

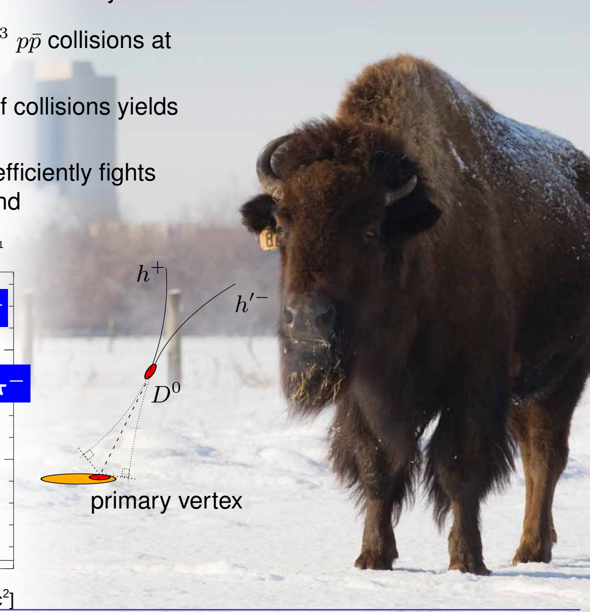
- If so, enhanced CP violation may be present as well...

Charm at the Tevatron

World's largest sample of $D^0 \to h^+ h'^-$ decays

- 10 years of operations: $\sim 10^{13}$ $p\bar{p}$ collisions at 1.96 TeV
- high $c\bar{c}$ cross section: $\sim 1\%$ of collisions yields a D meson
- trigger on displaced vertices efficiently fights huge combinatorial background



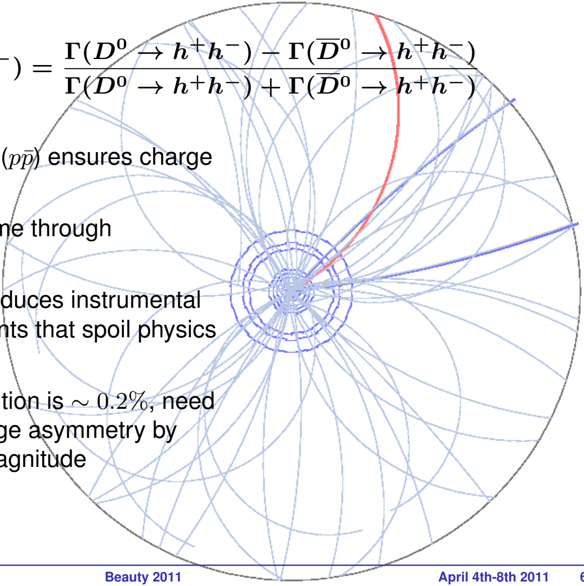


CP asymmetry in $D^0 \to h^+h^-$ decays

What do we measure?

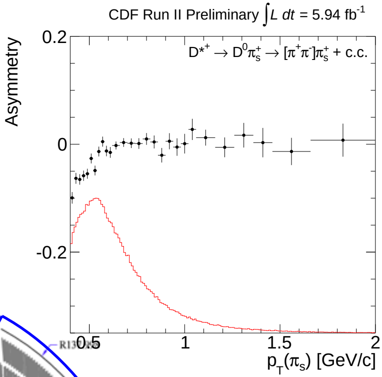
$$A_{\text{CP}}(D^0 \to h^+h^-) = \frac{\Gamma(D^0 \to h^+h^-) - \Gamma(\overline{D}^0 \to h^+h^-)}{\Gamma(D^0 \to h^+h^-) + \Gamma(\overline{D}^0 \to h^+h^-)}$$

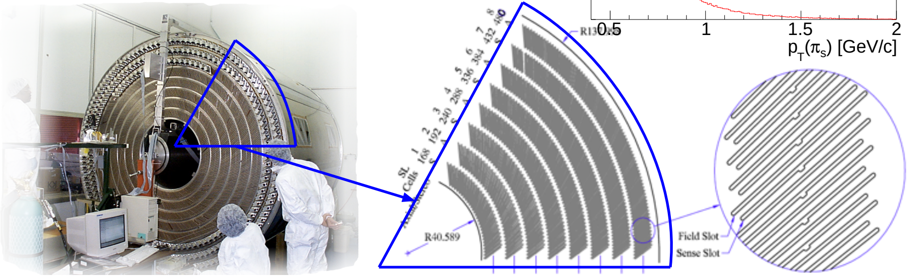
- CP symmetric initial state ($p\bar{p}$) ensures charge symmetric production
- Tag flavor at production time through $D^{\star +} \to D^0 \pi_s^+$ decay
- Additional charged pion induces instrumental asymmetries of few percents that spoil physics asymmetry
- Expected statistical resolution is $\sim 0.2\%$, need to suppress detector charge asymmetry by more than one order of magnitude



CDF not charge-symmetric

- ✓ Central drift chamber has cells tilt of 35° wrt radial direction
- ✓ Positive and negative particles hit cells at different angles
- ✓ Positive and negative pions have differences in absorption rates
- ✓ Asymmetry in reconstruction efficiency particularly large at low momentum





How are we doing it?

Combine the "raw" asymmetries of three different event samples to minimize systematic errors caused by the detector induced asymmetries:

✓ $D^\star \to D^0\pi_s \to [h\,h]\,\pi_s$ $\qquad A(hh^\star) = A_{\mathrm{CP}}(hh) + \delta(\pi_s)$

cancel asymmetry due to π_s^+/π_s^- different reconstruction efficiencies

✓ $D^\star \to D^0\pi_s \to [K\pi]\,\pi_s$ $\qquad A(K\pi^\star) = A_{\mathrm{CP}}(K\pi) + \delta(\pi_s) + \delta(K\pi)$

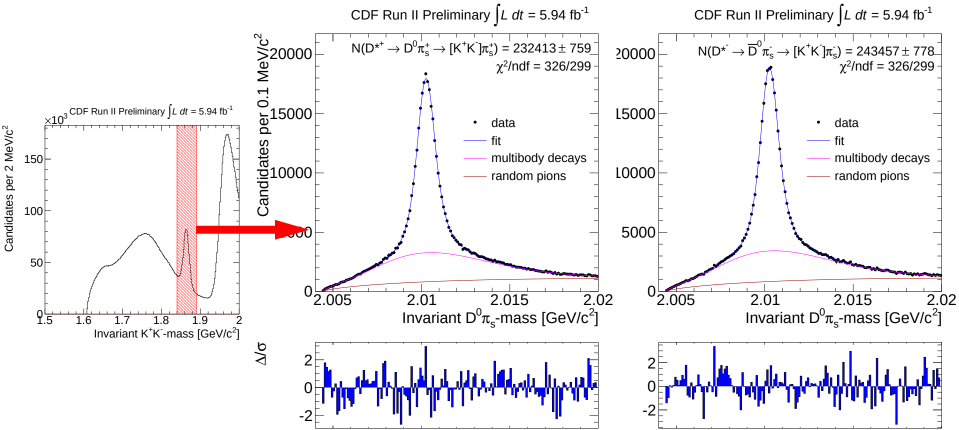
cancel asymmetry due to K^+/K^- different interaction with matter $+$ possible CPV in $D^0 \to K\pi$

✓ $D^0 \to [K\pi]$ $\qquad A(K\pi) = A_{\mathrm{CP}}(K\pi) + \delta(K\pi)$

The physical A_{CP} could be extracted through the combination:

$$A_{\mathrm{CP}}(hh) = A(hh^\star) - A(K\pi^\star) + A(K\pi)$$

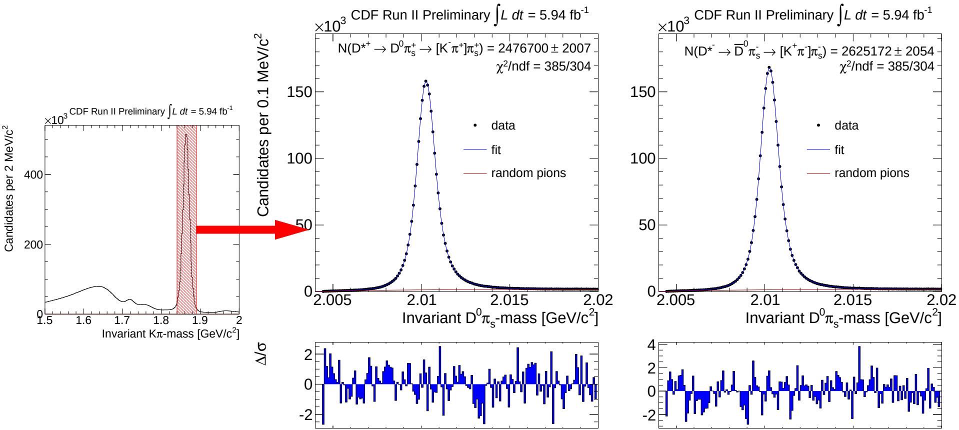
Counting $D^\star$-tagged $D^0 \to K^+K^-$



$\sim 476\,000$ $D^\star$-tagged $D^0 \to KK$

$$\boldsymbol{A(KK^\star) = (-2.32 \pm 0.21)\%}$$

Counting $D^\star$-tagged $D^0 \to K^-\pi^+$

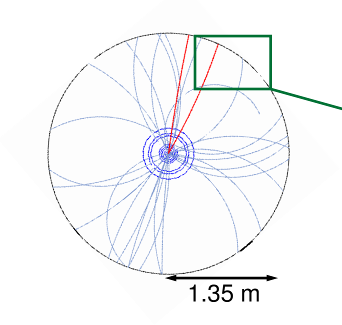


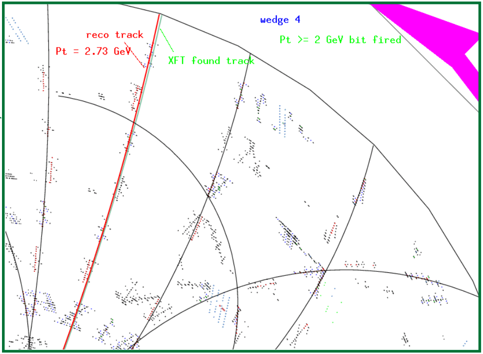
$$\sim 5'000'000\ D^\star\text{-tagged } D^0 \to K\pi$$

$$\boldsymbol{A(K\pi^\star) = (-2.91 \pm 0.05)\%}$$

Untagged $D^0 \to K^-\pi^+$ sample

✓ No pion to tell which is D^0 and which is $\overline{D}^0$...

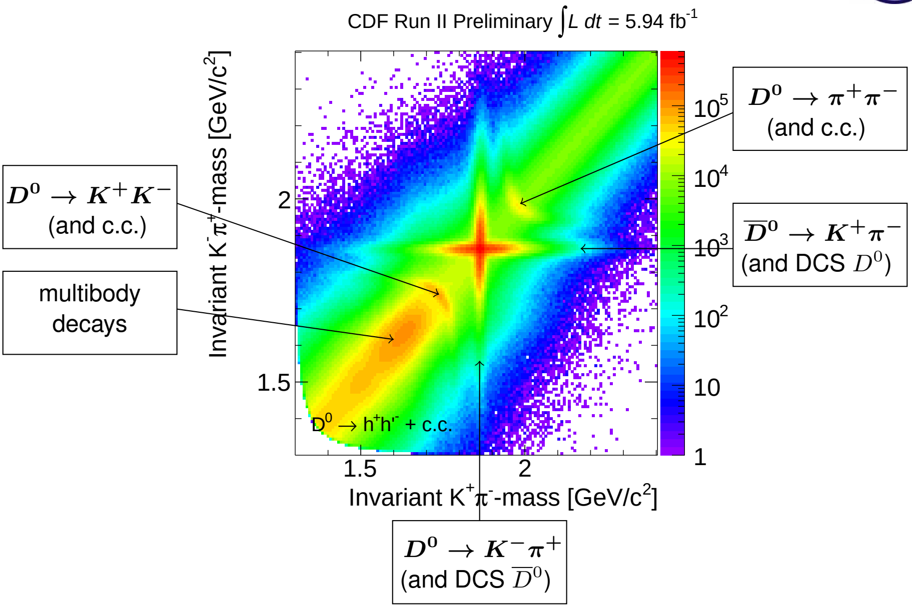




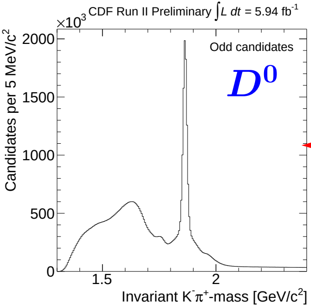
✓ ...but excellent mass/momentum resolution allows separation of $K^-\pi^+$ and $K^+\pi^-$ final state without PID information

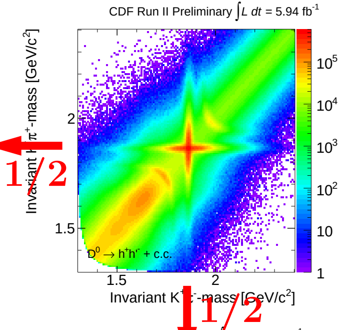
- Tracks curved by 1.4 T axial magnetic field and sampled in 96 points (each 150 microns accurate) $\longrightarrow$ $\sigma(p_T)/p_T^2 \sim 0.15\%$ (GeV/c)$^{-1}$

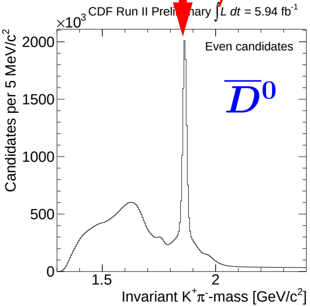
Untagged $D^0 \to K^-\pi^+$ sample



Counting untagged $D^0 \to K^-\pi^+$

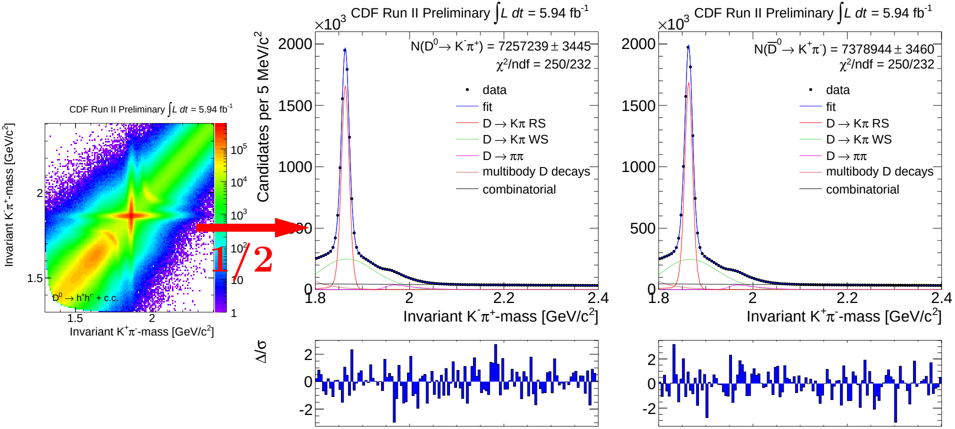






- ✓ two statistically independent samples with half the events each
- ✓ can easily afford to loose a factor of two in statistics here
- ✓ signal is in narrow peak (ignore 0.4% DCS contribution)

Counting untagged $D^0 \to K^-\pi^+$



$\sim 2 \times 15^{\cdot}000^{\cdot}000$ untagged $D^0 \to K\pi$

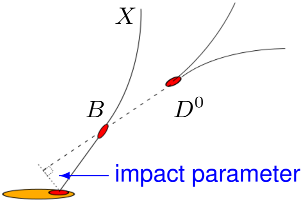
$$\boldsymbol{A(K\pi) = (-0.83 \pm 0.03)\%}$$

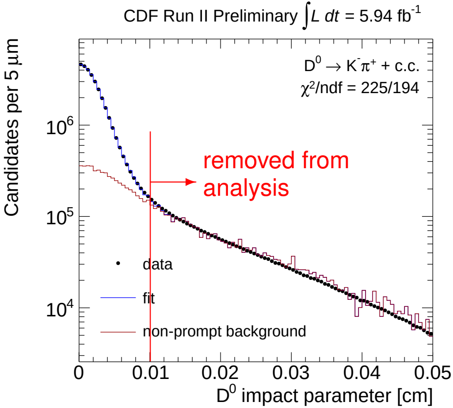
Systematic Uncertainties

Source of systematic uncertainty	$\Delta A_{\text{CP}}(\pi^+\pi^-)$	$\Delta A_{\text{CP}}(K^+K^-)$
Approximations in the method	0.009%	0.009%
Beam drag effects	0.004%	0.004%
Contamination of non-prompt D^0 decays	0.034%	0.034%
Shapes used in fits	0.010%	0.058%
Shapes charge differences	0.098%	0.052%
Asymmetries from non-subtracted backgrounds	0.018%	0.045%
Imperfect sample reweighing	0.0005%	0.0005%
Sum in quadrature	0.105%	0.097%

- Intrinsically suppressed by data-driven method
- Major offenders: effects that impact differently D^0 and $\overline{D}^0$, e. g.
  - Charge-dependent differences in mass shape
  - Possible asymmetric contribution of D from B decays

Contamination from $B \to D^0 X$ decays





- $c\tau(B) \approx 450$ microns, D from B have non-zero impact parameter
- 100 microns cut removes most of them but still 17% of our candidates are likely to come from a B decay
- Inverted and analysis repeated on events enriched in D from B
- Asymmetry in the sideband is consistent with the central one, then we evaluate

$$A_{\text{CP}}(B \to D^0 X) = (-0.21 \pm 0.20)\%$$

- Assign $0.17 \cdot A_{\text{CP}}(B \to D^0 X)$ systematic

Final results

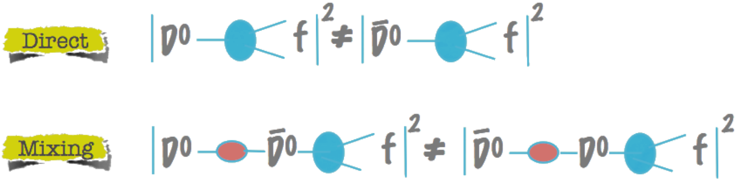
$A_{CP}(D^0 \to \pi^+\pi^-)$	$[+0.22 \pm 0.24\ (stat.) \pm 0.11\ (syst.)]\%$
BaBar 2008	$[-0.24 \pm 0.52\ (stat.) \pm 0.22\ (syst.)]\%$
Belle 2008	$[+0.43 \pm 0.52\ (stat.) \pm 0.12\ (syst.)]\%$
$A_{CP}(D^0 \to K^+K^-)$	$[-0.24 \pm 0.22\ (stat.) \pm 0.10\ (syst.)]\%$
BaBar 2008	$[+0.00 \pm 0.34\ (stat.) \pm 0.13\ (syst.)]\%$
Belle 2008	$[-0.43 \pm 0.30\ (stat.) \pm 0.11\ (syst.)]\%$

World's most precise measurements... but still no evidence for CPV

Babar 2008 = *Phys. Rev. Lett.* **100** (2008) 061803
Belle 2008 = *Phys. Lett.* **B 670** (2008) 190

Interpretation

The time-integrated asymmetry receives contribution from both direct and indirect sources of CPV



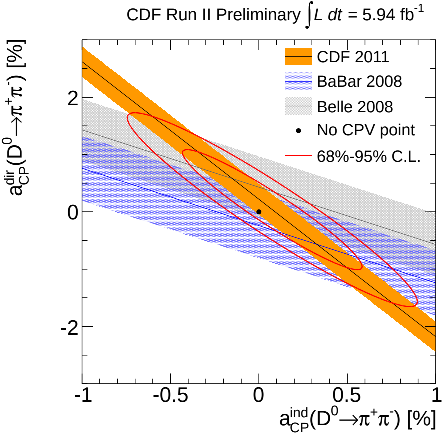
Since flavour mixing parameters are small in the charm sector, at first order, the measured asymmetry is the linear combination of the two terms

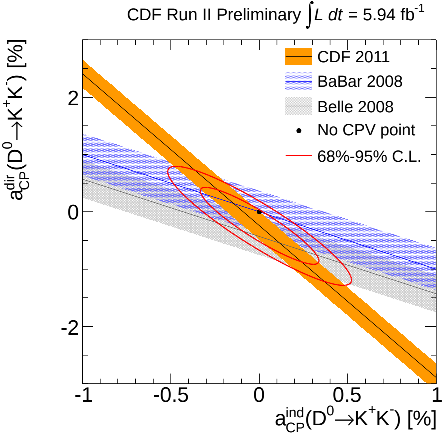
$$A_{\text{CP}}(h^+h^-) \approx a_{\text{CP}}^{\text{dir}} + \frac{\langle t \rangle}{\tau} a_{\text{CP}}^{\text{ind}}$$

where $\langle t \rangle / \tau$ is the mean value of the D^0 meson proper decay-time in unit of lifetimes

Direct vs indirect CPV

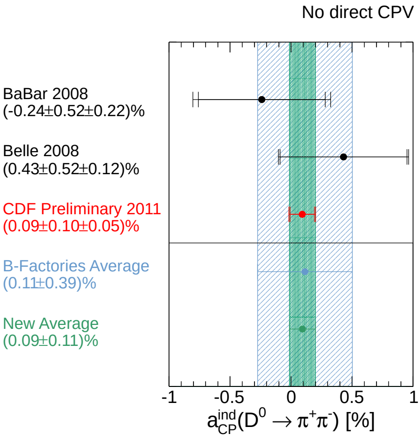
$$A_{\text{CP}}(h^+h^-) \approx a_{\text{CP}}^{\text{dir}} + \frac{\langle t \rangle}{\tau} a_{\text{CP}}^{\text{ind}}$$

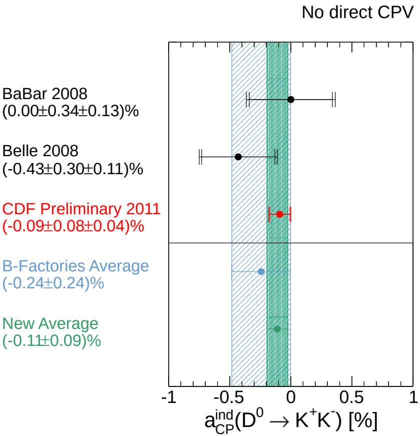




Thanks to CDF trigger bias $\langle t \rangle / \tau > 1$, our measurements are complementary to B-factories ones

Comparison assuming CPV just in mixing





Or combining the CDF measurements in the two channels:

$$a_{\text{CP}}^{\text{ind}} = [-0.01 \pm 0.08]\,\%$$

Conclusions

- After many years of dedicated experiment we finally reached enough precision to probe the charm sector for NP in a significant way
- Nobody (not even us) believed this could happen at the Tevatron
- Shown recent results on CPV in $D^0 \to h^+h^-$ decays:
  - world's most precise measurements (for years to come)
  - mixing-induced effects $\gtrsim 0.15\%$ excluded
  - theorists are already picking up on this [arXiv:1103.5785]
- High precision measurements competitive or even superior to the B-factories are possible at the Tevatron